CONCRETIONS IN STREAMS FORMED BY THE AGENCY OF BLUE GREEN ALGÆ AND RELATED PLANTS.

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In 1898, I discovered that concretionary formations occurred in Little Conestoga Creek, Lancaster County, Pa. At that time, however, I was engaged in other studies and gave the concretions only a passing notice. But in the late summer of 1914, my attention was directed to the subject again by the reading of Dr. Walcott's paper on "Pre-Cambrian Algonkian Algal Formations" which appeared July 22, 1914. This paper made me realize the importance of a careful investigation of these particular stream formations as to characteristics, distribution, origin, etc. I began at once a careful and extended search in the Little Conestoga as well as in other streams for concretionary structures of recent formation. My search was amply rewarded by finding them in great quantities, and distributed throughout nearly the entire length of the Little Conestoga. I found also that they not only occur in the creek itself, but that quite large deposits of the concretions underlie the flood plain meadows along the creek banks. One of these in Kendig's Woods, two miles southwest of Millersville, Pa., is made up wholly of concretionary materials on the top of which forest trees of large size and considerable age are growing. This deposit covers nearly an acre to the depth of about 8 feet in the middle thinning out lenslike toward its edges. Another deposit along the same stream near Fruitville in Evan's Meadow, more extensive in area but of slighter depth, forms a substratum under a thick soil cover and has an average depth of about two feet. Deposited concretions occur under similar conditions in many other of the meadows along the stream as is shown by weathered concretions occurring in the soil and wash wherever wet-weather stream gullies have been torn through the soil cover.

Though these structures, as I shall show later on, are without doubt due to Algoid agency in the stream waters, it may be well to premise the full discussion of their origin by somewhat complete descriptions of their characteristics as to form, size, structure, etc. In this way the attention of botanists and geologists will be directed to their study and distribution, so that their significance as agents of rock formation and the flora, responsible for their growth, may be fully worked out.

Size and Shape.—The concretions both in the stream and in the deposits vary in size from peas to masses nearly a foot in diameter (see Fig. 1). The latter size is not very common in the

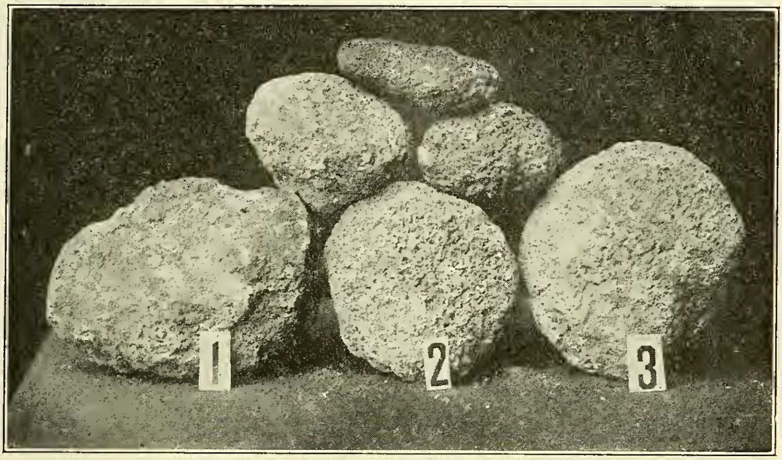

FIG. 1. A group of the concretions showing their size, shape, surface appearance and color. No. 1 is 7½x10 inches; No. 2 is about 5 inches in face diameter and 3 inches thick; No. 3 is 8x7x5 inches. The two smaller concretions above are typical, both in color and surface appearance, of growing specimens.

stream but many large concretions occur in the deposits probably because the smaller ones after deposition in land forms have been carried away in solution by percolating waters leaving only the larger forms. In the flood deposits in Kendig's Woods thousands of the concretions when I found the deposit last summer measured nearly a foot in length and six inches or more in transverse diameter.

The smaller concretions are invariably ellipsoidal in shape (see Fig. 1), and quite symmetrical unless broken by flood action. The larger sized concretions, though of the same general shape, are less symmetrical. Those in the stream are nearly always more regularly ellipsoidal than those of the deposits in flood plains and stream bars. This is, no doubt, due to their weathering through solution or to their having been broken by flood waters during their transportation to their present positions.

The concretions in the stream are quite firm in texture; those in the deposits are less compact. Both are porous and roughly coralline in general appearance and internal structure.

In color they vary from bluish green to whitish. The growing specimens in the stream are generally bluish green. All specimens after exposure for some time to sun, air, and rain or to the action of soil waters become grayish white.

Composition and Hardness.—Though the composition varies slightly from place to place yet all are limy deposits concentric around a nucleus. The main constituents in the concentric layers are calcium carbonate, silica and organic matter of vegetable origin. Upon dissolving out the limy constituents with dilute hydrochloric acid, a mat is often left of vegetable materials composed of the matted stems or tissues and cells of low type plants such as mosses and algæ.

Few of the specimens tested had a hardness as great as that of common calcite, most of them being about two in the scale of hardness. The weathered concretions are generally less coherent than those now forming in the stream.

The following table shows the main constituents of the concretions:

Constituents.	*A.*	*B.*
Organic matter	10% to 15%	1 to 12%
H_2O	1%	1%
SiO_2	12%	12%
$CaCO_3$	60% to 75%	70 to 80%
Fe	1%	2%
Al	Trace	Trace
$MgCO_3$	Trace to 1%	Trace to 1%

A of growing specimens.
B of specimens from flood plain deposit.

Structure.—Most specimens have as the nucleus a quartz or limestone pebble of the country rock. Near Millersville, where the stream flows for a mile or two parallel to an igneous dyke, the nuclei are diabase pebbles. But some specimens lack the stony nucleus having instead the limy layers concentric around a dark spot which proves upon close examination to be carbonaceous matter resembling nearly structureless peat. Probably this was originally a piece of wood or other vegetable tissue that carbonized after the concretionary laminæ had accumulated around it. This supposition has been verified in a number of cases by finding concretions with organic matter as nuclei (see Fig. 2).

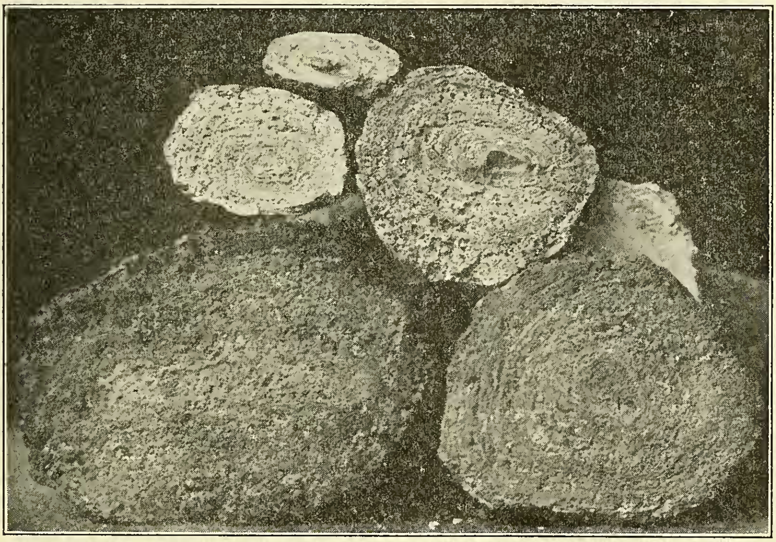

FIG. 2. Sections of a group of the concretions showing the laminae, concentric arrangement of the laminæ, the nucleus or nuclear point, and eccentric manner of growth. One-third natural size. The nucleus in the small upper specimen is a small water worn quartz pebble. The larger upper specimen shows where the nucleus was broken out when the section was made.

The concretions with stony nuclei may always be detected by their higher specific gravity.

Around the nucleus of a specimen is layer on layer of the limy matter each lamina from one eighth to one fourth of an inch in thickness. The laminæ are not equally compact throughout their thickness, but are open and porous within and quite solid without. A polished section of any concretion exhibits many concentric ellipsoidal layers with the nucleus nearly always eccentric and the successive layers with a greater thickness on the one side and two ends than on the other side. The thickness of the successive laminæ in any one direction out from the nucleus is nearly uniform. In other words, along any radius the inner layers are just as thick as the outer ones. When found in place in the stream where the concretions have not been disturbed for a long time, the down side laminæ are invariably a little thicker than those on the upper side. This indicates that the greater growth is downward.

In appearance and structure, the concretions of the Little Conestoga are very similar to the "Lake Balls" from Lake Canandaigua, New York, so vividly described by Dr. Clarke, under the name of "Water Biscuits." They are also somewhat similar though much larger in size to the oölitic sands found forming in great numbers in the waters of Great Salt Lake by A. Rothpletz and traced by him to the agency of blue green algæ.

Where Found.—Upon recognizing the importance of a thorough study of the Algoid concretions, I began a systematic search in all parts of the Little Conestoga as well as in other streams of both Lancaster and York Counties, Pennsylvania. My search showed that these objects abound in all parts of the Little Conestoga nearly from source to mouth. But no other streams in this part of the state have so far yielded any specimens. Those found in the sand bar in Lake Canandaigua near the mouth of Sucker Brook are probably also of stream origin, and I feel confident that a careful search in the brook would reveal at least some, if not many, of the concretions. Substances somewhat similar in composition occur in other lakes than Canandaigua though they do not have the concretionary form. Thus laminated reef-like accumulations of Algoid origin occur in Round Lake, New York, while marly or tufaceous deposits have accumulated for ages and are still forming in many lakes in Michigan, Wisconsin and Indiana. The tufa and thinolite described by Russell as forming in Pyramid Lake, Nevada, are now regarded as of similar origin though differing much from the Little Conestoga concretions in both form and structure.

That concretions similar to those found in the Little Conestoga occur in other streams is evident from observations made in Center County, Pennsylvania, by Dr. Wieland, who, however, had not recognized them as of Algoid origin until I called his attention to the well known activity of some algæ in precipitating calcium carbonate. In a recent personal letter to me Dr. Wieland describes concretions that he found in 1888 in a stream near Lemont, Center County, Pa. He, however, says, "I just thought of them as very interesting objects from the viewpoint that they showed once more how abundant is CO_2 whether derived from plants or other sources. In short I knew too much and too little to make the least use of what I found."

Origin.—In 1854, W. Ketchell in the First Annual Report of the Geological Survey of New Jersey refers to *Chara* as active agents in the formation of fresh water marl. In 1864 Frederick Cohn found that a number of aquatic plants, especially *Chara* Mosses and Algæ, caused the deposition of travertine at the waterfalls of Tivoli. The deposition he attributed to the activity of the plants in absorbing carbon dioxide and so setting the lime carbonate free. That is, these low type plants consume carbon dioxide and exhale oxygen. When this is done in water containing calcium bicarbonate they deprive that salt of its second molecule of carbonic acid and the insoluble neutral carbonate of lime is precipitated.

W. S. Blatchley and G. H. Ashley in their report on the lakes of Indiana in 1900 also refer to the activity of plants in the precipitation of insoluble lime carbonate. But they also thought that the dissolved lime brought into the lakes by streams and deposited mechanically by evaporation was a more important agency than the plants.

In 1900 C. A. Davis discussed the origin of the marls of the lakes of Michigan and came essentially to the same conclusion as Cohn. He says:

"But in water containing amounts of salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the folllowing chemical equation, $CaH_2(CO_3)_2 + O \rightarrow H_2O + CaCO_3 + CO_2 + O$, in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants and both carbon dioxide and oxygen set free, the free oxygen possibly acting still further to precipitate more calcium monocarbonate, $CaCO_3$."

Dr. F. W. Clarke in "Data of Geochemistry" says:

"That Dr. Davis' theoretical equation (given above) rests on no experimental basis."

In an article in *Science* dated December 14, 1914, J. Claude Jones, of the University of Nevada, says that the tufas of Salton Sea and of Pyramid Lake owe their origin to blue green algæ. He shows that wherever these plants are present in Pyramid Lake the gravels are cemented together and wherever the algæ are absent no trace of the tufas can be found.

Dr. Clarke ascribes the origin of the "Water Biscuits" of Lake Canandaigua to the same agency.

Miss Josephine Tilden in *Minnesota Algæ* (1910) says that *Gleocapsa calcarea* forms a calcareous crust (with other lime secreting forms) on boards where spring water from a trough drips down constantly.

Weed in his classic report (1889, U. S. G. S.) on the rock formations of the hot springs of the Yellowstone National Park shows that travertine as well as siliceous sinter are deposited through the aid of algæ.

Dr. B. M. Davis, of the University of Pennsylvania in a very interesting paper (*Science,* Vol. VI., July 30, 1897) describes the algæ and bacteria active in the formation of the travertine and siliceous sinter deposits in Yellowstone Park.

Dr. MacFarlane, of the University of Pennsylvania, in speaking of the activities of thermophilic algæ of hot spring and geyser regions, ascribes many rock formations throughout the earth's history as due to the work of fresh water algæ especially of the group Cyanophyceæ.

Evidences That the Active Agents of the Concretionary Formations in the Little Conestoga are Blue Green Algæ.

That the concretions described in the first part of this paper are the result of life processes of plants may be proved in a number of different ways. (1) The color of all growing specimens in the stream is the characteristic bluish green color of the Cyanophyceæ, while those exposed to rain and sunshine are grayish white. Careful microscopic examination also of such growing specimens reveals a varied thallophytic flora mainly of the Cyanophyceæ. Species of the genera *Gleocapsa, Gleotheca, Aphanocapsa, Nostoc, Oscillatoria* and *Rivularia* have been identified. Associated with these are several of the green algæ (Chlorophyceæ). Many species of the Diatomaceæ and Desmidaceæ which generally live in close association with blue green algæ have also been identified and have, no doubt, contributed the siliceous matter which is disseminated through the calcareous matrix. Among the diatoms, species of the genus *Navicula* both in free forms as well as stalked forms on algæ are quite prominent. The *Charas* are also occasionally present, contributing a small percentage of so-called marly material. Some bacteria have also been found in association with the other plants but the bacteria have probably had little to do with the calcareous deposition, but may contribute the iron which I find present in every concretion that I have analyzed.

(2) The arrangement and structure of the laminæ also favors the view that these concretionary accumulation are due to life processes. That periodic accretion alternates with a period of quiescence is shown plainly by the concentric laminations of nearly uniform thickness. The open porous nature of each lamina within and the more solid character without, like the concentric arrangement, is due without doubt to the seasonal conditions of the region. Since algæ are essentially thermophilic plants, each winter destroys many of them and stops the growth of most of the rest and thus at the beginning of the plant year (spring) few and widely scattered algæ at first produce slow and scattered accretion of the limy matter; later the plants become more abundant and by summer they are crowded over the surface of each mass. This distribution of the algæ seasonally would naturally have its effects upon the struc-

ture and arrangement of the limy matter giving a decided though rough coralline appearance to the inside portion and a more compact texture to the outer part. The theory just given has been confirmed by a study of the distribution of the algæ on the concretionary bodies through the seasons. The fact also that when the limy matter is dissolved out with acids, a mat of vegetable chains and cells remains nearly as large as the original concretion is also confirmatory. Even in the concretions which are centuries old as those in the forest covered deposit in Kendig's Woods the dead cells and chains of blue green algæ may be found.

(3) Lime secreting algæ are found in the Little Conestoga during the entire year but abound from May till December. They occur not only in the water but encrust many objects, in a few places forming small reef-like accumulations similar to those in Round Lake, New York.

(4) Quite an array of investigators, among whom we may mention Agassiz, Bigelow, Gardiner, Murray, Finckle, Vaughan, Walther, Drew, Matson, Dall, and Sanford, have studied at first hand the activities of algæ of the genera *Lithothamnion* and *Halimeda* and also some of the bacteria in various parts of the ocean and in many seas. All have come to the conclusion that many of the so-called coral reefs owe their existence partly and often largely to the activities of these lowly plants. The Bermudas, the Bahamas, the Laccadive and Maldive Archipelagoes, Funafuti, and extensive rock beds in the Floridian Peninsula have all originated through plant agency as much as through coral polyps. If this be true, it is not only possible but probable that fresh water blue green algæ throughout all the ages have caused and are still causing the precipitation of rock materials from minerals in solution in streams and fresh water lakes.

(5) Weed has proved that the concretions formed in geyser basins and known as Geyserites are formed by algæ which through life processes cause the precipitation of the siliceous matter held in solution in the hot water.

(6) The observation that the laminar accretion seems to proceed more rapidly on the under side of a concretion proves that the formations are not due to mechanical precipitation of lime carbonate

through evaporation or change of temperature. It does, however, suggest that the secretion or precipitation is chemical and dependent on a life process that produces conditions for chemical reaction where the plants or animals are most abundant.

(7) Conway MacMillan in *Minnesota Plant Life* says:

"Some slime moulds have the power of incrusting their tiny fruit bodies with lime which they extract from their soil or from rain water which falls upon them. Such forms are often observed in Minnesota upon dead wood or fallen leaves, generally, in moist shady places in the deep forest. Some of the blue green algæ have the power of encrusting themselves with lime and in watering troughs and tanks there sometimes occurs a calcareous formation reminding one of the deposit in old tea-kettles. Such a crust is true limestone extracted from the water by the chemical activities of the algæ."

Upon a larger scale the blue green algæ have been conclusively shown by Weed to be important factors in travertine formation in the hot springs and geysers of Yellowstone National Park.

Dr. MacFarlane without knowing of my discovery in the Little Conestoga Creek has expressed the opinion that these apparently insignificant plants have throughout all the ages played and are still playing in all waters an important part in the formation of limestones and dolomites.

(8) The fact that many more or less ancient rocks have been demonstrated to be of algoid origin by various scientists and are similar to the Little Conestoga concretions in their concretionary or laminated structures or both is favorable to the view that algæ are just as important agencies in rock formations in the present geological epoch as in the past. The similarity of *Cryptozoön proliferum,* Ozarkian oölitic formations, *Newlandia frondosa, Camasia spongiosa, Collenia compacta, Collenia undosa* and other structural forms in rock formations to the work of recent algæ in hot spring and geyser regions has been vividly shown by Walcott, Wieland, B. M. Davis and others. Some, at least, of the above-named formations can be strikingly duplicated in their structural peculiarities by the Little Conestoga concretions and reef-like masses of Round Lake,—the Potsdam-Hoyt formation of New York state being especially like what would result were infiltrating waters, cementation, and other solidifying agents or processes to act for a long time upon the great mass of flood deposited concretions of the Little Conestoga in Kendig's Woods.

Mineral Content of the Little Conestoga Waters.

One would infer from the number of concretions growing in the Little Conestoga and also from the thickness of each lamina in a concretion that the mineral content of this stream's waters is high. I have verified this by determining the salinity of the stream under varying conditions. The salinity in a wet month was 330 parts in a million, while in a dry month this rose to 365 parts in a million. Streams in which I have found no trace of concretionary structures have a much lower salinity, the Big Conestoga Creek for example having a salinity of 190, the Pequea Creek 195, and the Susquehanna, in March, above the mouth of the Pequea and below the mouth of the Big Conestoga, about 200 parts in a million. The various springs flowing into the Little Conestoga have an average salinity nearly as high as that of the Little Conestoga itself.

The basin of the Little Conestoga is underlain with much more soluble limestone than any of the other streams so far investigated. This accounts for the high salinity of its waters and also for the distribution of the concretions so far as we know that distribution. Further search and study will certainly reveal that many streams of the world contain concretionary structures and determine the conditions of their distribution and formation. I trust the beginning I have made in the investigation of stream concretions will lead to a wide and thorough study of this interesting and important biological as well as geological problem.

The various facts tabulated on page 257 and correlated with the fact that the blue green algæ are about equally abundant in the various streams mentioned in the table would seem to indicate that deposition of $CaH_2(CO_3)_2$ is always going on in all the streams during the growing season, but that when the salinity is low solution by the stream waters balances deposition and no concretions are formed. When, however, the salinity is high, solution can not take place and laminated structures due to seasonal or other changes are formed either in concretionary form or more rarely as reefs. This is put forward as a working hypothesis, many more observations and analyses are needed however before the various problems connected with these formations can be fully solved.

Table Showing Relation Between the Salinity of Streams and the Presence of Calcium Carbonate Concretions.

Stream or Spring.	Month.	Salinity, Parts in One Million.	Nature of Salinity (Chiefly).	Concretions Present in Stream.
1. Little Conestoga	Feb. 5	330	$CaH_2(CO_3)_2$	Abundant
2. Little Conestoga	March	300	"	"
3. Little Conestoga	April	365	"	"
4. Branch Run, tributary to Little Conestoga	April	91	"	None
5. Big Conestoga	Feb.	152	"	None
6. Big Conestoga	March	100	"	None
7. Big Conestoga	April	150	"	None but many gasteropods
8. Duing's Run, tributary to Big Conestoga	April	195	"	None
9. Pequea Creek	April	195	"	None
10. Donegal Run	April	404	"	Abundant
11. Nissley's Dam in Donegal Run, further upstream than 10	April	400	"	Many but small
12. Donegal Run near source	April	230	"	None
13. Bellaire Branch of Donegal Run	April	208	"	None except near mouth
14. Little Chickies	April	170	"	None
15. Big Chickies	April	171	"	None
16. Big Chickies farther upstream	April	174	"	None

Further Notes on Concretionary Formations in Streams.

Since writing the above I have been fortunate enough to find a new locality for concretions. Knowing that Donegal Township, Lancaster County, comprised a notably large area of Cambro-Ordovician limestones, I judged that its streams would be favorable to the growth of calcareous concretions through the agency of blue green algæ. Search on April 25, in Donegal Creek, revealed these objects in greater abundance than in the Little Conestoga. One meadow of fully 12 acres bordering the stream about one mile northeast of Marietta was found to be underlain with a bed of concretions not less than a foot in average thickness throughout its entire extent. And this was under a soil cover of more than a foot in depth that had, apparently, resulted from the weathering and disintegration of the same objects. The great flood deposits of concretions in this and neighboring meadows were paralleled by large quantities in the stream itself, fully one fifth of the stones in some places in the stream channel being of concretionary origin as shown by their shape, laminated structure, and composition.

The finding of the new locality is of great interest. It shows that a careful, intelligent, and systematic search will reveal these formations in many other regions of the world wherever the proper conditions exist for calcareous and siliceous precipitation through the life processes of plants.

But the geological significance of the great meadow deposits also needs emphasis. The large accumulation in the Donegal Township Meadow represents a comparatively long period and this indicates a considerable antiquity of the plants which form the concretions. Then too, such a bed of closely packed concretions is highly suggestive of the manner in which some ancient rock beds originated. For were such accumulations of concretions as those in the Donegal Meadows to be consolidated by the action of infiltrating waters, pressure, heat and chemical change solid rock beds would result nodular in appearance and concretionary in structure hardly distinguishable from the Hoyt Potsdam beds of New York.

Species of the following genera of the Cyanophyceæ are found associated with the calcareous concretions occurring in Donegal Creek, Lancaster County, Pa..: *Glœocapsa, Microcystis, Cœlosphærium, Aphanocapsa, Oscillatoria, Rivularia, Nostoc, Chroococcus.* There are also species of *Protococcus,* many species of Diatoms, several species of Desmids, various species of the Chlorophyceæ, several species of Phæophyceæ, and species of Rhodophyceæ.